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# Analysis of Agricultural Nonpoint Pollution Control Options in the St. Albans Bay Watershed

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ORIGINAL

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## ABSTRACT

This report used a computer model, the Agricultural Nonpoint Source Pollution Model (AGNPS), to estimate nutrient losses both within the watershed at the field scale and at the watershed outlet. The capability of AGNPS to evaluate problem sites within a watershed can assist nonpoint pollution program administrators in targeting best management practices (BMP's). We concluded that substantial water quality improvements are possible from barnyard runoff control, animal waste storage structures, and timely nutrient applications.

Keywords: Manure management, best management practices, Rural Clean Water Program, farm income, dairy farming, nonpoint source pollution, targeting, Agricultural Nonpoint Source Pollution Model.

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## PREFACE

The U.S. Congress enacted the Rural Clean Water Program (RCWP) in 1979 as an experimental program to combat agricultural nonpoint pollution. RCWP, a voluntary program, provides long-term financial and technical assistance to owners of privately held agricultural land in selected project areas to install and maintain best management practices to control water pollution. The Agricultural Stabilization and Conservation Service (ASCS), U.S. Department of Agriculture (USDA), operates the program with technical assistance provided by other USDA agencies and the U.S. Environmental Protection Agency (EPA). The Soil Conservation Service (SCS), USDA, coordinates all technical services.

The St. Albans Bay RCWP project (Franklin County, VT) was one of five projects selected for comprehensive monitoring and evaluation of physical and economic effects of the RCWP projects. The Economic Research Service, USDA, is cooperating with the ASCS (Burlington, VT), SCS (Winooski, VT), and the University of Vermont, Water Resources Research Center and Extension Service (Burlington, VT) in conducting the economic evaluation.

The economic evaluation includes determining RCWP effects on participants and local agriculture, evaluating offsite and community impacts, analyzing cost effectiveness of the projects, and comparing the projects' benefits and costs. This report projects the potential water quality improvements from implementing best management practices and demonstrates a methodological tool that can be used for other nonpoint pollution projects.

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## SUMMARY

Agricultural nonpoint pollution due to animal waste has been a problem for policymakers for nearly two decades. The Federal Rural Clean Water Program (RCWP) experimented in reducing surface water contamination in 21 agricultural watersheds around the Nation. This study investigates potential water quality improvements from RCWP at St. Albans Bay, VT. A computer model, the Agricultural Nonpoint Source Pollution Model (AGNPS), was used to estimate nutrient losses at the field and watershed scales. Computer modeling can be used to reduce the uncertainty associated with the effectiveness of best management practices (BMP's) for controlling water pollution. Detailed analysis suggests that BMP's can improve surface water quality. Our findings included:

1. Improvements to barnyards, such as controlling runoff by diversion systems or sod buffer strips, reduced nitrogen (N) and phosphorus (P) concentrations at the watershed outlet by as much as 7 percent.

2. Implemented BMP's can cause substantial reductions in N, P, and chemical oxygen demand (COD) losses during storms. The reductions were greatest in March due to animal waste storage structures (AWSS) that eliminated the need for spreading manure daily.

3. Farms located along water channels near the watershed outlet had a larger impact on watershed water quality than inland farms.

4. The initial levels of N and P losses have an important effect on relative abatement costs and often are more significant in determining relative abatement costs than the type of manure storage structure selected.

5. Often the marginal cost of P loss abatement associated with agricultural BMP's may exceed the marginal abatement costs of P removal from point sources. Improving existing point sources may initially be more cost effective than proceeding with nonpoint abatement activities.

6. Long-term water quality improvements depend on the farmer as a nutrient manager. If fall applications of nutrients are not incorporated on cornland, the water quality gains from installing an AWSS are reduced or eliminated.

7. The capability of AGNPS to evaluate pollution problems within a watershed can assist nonpoint pollution program administrators in targeting BMP's. This and similar models can be used for screening watersheds to determine which ones can attain water quality improvements by BMP implementation and where the BMP's would be most effective.

# Analysis of Agricultural Nonpoint Pollution Control Options in the St. Albans Bay Watershed

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## INTRODUCTION

The Rural Clean Water Program (RCWP) was implemented in 1980, following a provision of the 1977 Clean Water Act amendments to the Federal Water Pollution Control Act. As part of RCWP, 21 watersheds were selected for monitoring, intensive planning, and nonpoint pollution program implementation. These projects had a 10-year time limit, 5 years for contracting and 5 more to complete implementation, and a $70-million budget (3).1/

One of the projects selected for the RCWP was the St. Albans Bay watershed, located on the eastern side of Lake Champlain, in northwestern Vermont. The St. Albans Bay watershed was selected because it had undergone a rapid decrease in water quality, characterized by annual noxious algal blooms, proliferation of rooted aquatic vegetation in shallow areas, an unpleasant odor, and water that was unsafe for human contact during part of the summer. These conditions reduced water recreational activities and property values along the bay (23). The Environmental Protection Agency (EPA) conducted studies that suggested phosphorus (P) and nitrogen (N) released from point and nonpoint sources were the major pollutants in St. Albans Bay (22).

An agricultural subwatershed was chosen to investigate the influence of agricultural nonpoint pollution in the RCWP project area. The Jewett Brook watershed is 84 percent agricultural land, with most of the remainder being woodland and no significant portion being urban (25). There are 18 dairy farms contained within the Jewett Brook watershed and parts of 3 others, representing about 21 percent of the farms in the St. Albans Bay drainage basin (9). Average farm size is about 225 acres, with a range from 120-435 acres. The average dairy herd has 84 milkers and 43 replacement stock, totaling 140 animal units (AU) per farm.2/

The primary agricultural pollution problems in the Jewett Brook watershed relate to animal-waste management. These include barnyard runoff, heavy and untimely applications of manure on some fields (such as during periods of high runoff and snow cover), milkhouse waste disposal, lack of vegetative buffer strips along streams, and free animal access to streams. We investigated in this report the potential water quality improvements from best management

1/ Underscored numbers in parentheses refer to items listed in References.
2/ An AU is defined as 1,000 pounds of animal live weight. For example, a 1,320-pound dairy cow represents 1.32 AU.

practices (BMP's) implemented with RCWP cost sharing. A personal computer (PC) model of watershed hydrology and water quality was used to estimate changes in concentrations of nitrogen, phosphorus, sediment, and chemical oxygen demand (COD) in runoff waters. This model, the Agricultural Nonpoint Source Pollution Model (AGNPS), was used to simulate water quality parameters before and after RCWP practices were contracted. AGNPS is an integrated watershed model that considers pollutant loadings from barnyards and farmland, as well as other land (woodland, wetland, and residential).

The computer simulation addressed a number of management concerns and provided a methodology for planning future agricultural nonpoint pollution control projects. One use of the AGNPS model is screening individual barnyards and fields within a watershed to determine which ones contribute more to water pollution. This screening allowed us to address our first objectives: evaluate the effectiveness of animal-waste management and sediment-control practices for improving water quality in an agricultural watershed. Storing manure and incorporating it to prevent runoff losses, along with vegetative buffer strips and other sediment-control practices, are expected to reduce both sediment-associated and dissolved nutrients in waterways. The AGNPS model estimates both phases of nutrient runoff. The implications of practices and their interactions as they result in tradeoffs of one phase of nutrient loss for another will be explored.

A second objective was to determine if the projected water quality improvements were accomplished cost effectively through RCWP. A related objective was to project how Government cost sharing could be more efficiently allocated to treat those significant pollution sources that will respond to BMP's. These objectives required us to identify sections of the watershed that were contributing most to pollution and to determine which land use features were important for BMP's to influence pollutant losses. Barnyards and the interaction of animal-waste management practices were of particular interest because of their role in the quality of watershed runoff.

The final objective was to evaluate the tradeoffs between farm income and the quality of farm runoff. With the Government paying 50-75 percent of the cost for implemented practices, it is assumed that farmers bear significant costs to protect water quality.

## JEWETT BROOK WATERSHED

The upper portion of Jewett Brook is one of seven subwatersheds that drain into St. Albans Bay. Jewett Brook flows through approximately 5 miles of flatlands and joins Stevens Brook at the headwaters of a wetland area before emptying into the bay. The types of soil in the watershed are mainly lacustrine sands, silts, clays, and glacial tills. These soils are generally considered highly erodible. Erosion is not a major problem in the watershed because the terrain is flat (9). The distribution of these soils is such that 92.5 percent of the soil is considered "poorly drained" (21). As a result, it is generally presumed that groundwater is not a water quality concern in this area. Cropland, accounting for 2,354 acres in the subwatershed, is composed of corn (807 acres) and hay (1,547 acres). There are approximately 485 acres of pastureland, and the remaining land (597 acres) consists of woodland and marshes (24).

Numerous BMP's are implemented in the Jewett Brook watershed as a result of RCWP. The BMP's are designed to reduce farm losses of sediment and nutrients and, thereby, to reduce nonpoint source pollution in St. Albans Bay. The BMP's used in the Jewett Brook watershed are summarized in appendix table 1. Although we analyzed the effects of these BMP's on the nutrient level of the watershed outflow using a personal computer model, we began by examining the results of water quality tests conducted by the Water Resources Research Center at the University of Vermont.

Water quality monitoring shows that Jewett Brook has the highest N and P concentrations and lowest dissolved oxygen level, compared with other monitored subwatersheds of St. Albans Bay (24). Concentrations of suspended solids have shown small increases since BMP's have begun to be implemented (table 1). This may be due to the substantial short-term increases in corn acreage (807 acres in 1985 versus 611 acres in 1982), which results in greater soil erosion, compared with other agricultural cropland. Total Kjeldahl N concentrations appear to be decreasing, according to regression results, although ammonia N is increasing (24). Average N concentrations at the watershed outlet of Jewett Brook are also shown in table 1. The projected reductions in total N may reflect better management of animal wastes. Average concentrations of P appear to be increasing (table 1). However, the variability during the year has decreased since the inception of RCWP (24).

The water quality data must be analyzed with caution, as they have limited potential to show the effects of BMP's implemented through RCWP. Rainfall patterns fluctuate, and nutrients trapped in field or stream sediments are released in varying amounts each year. All BMP's were not implemented during

Table 1--Annual mean values for water quality parameters sampled at the outlet of the Jewett Brook watershed

| Parameter | 1982 | 1983 | 1984 | 1985 |
|---|---|---|---|---|
| | Concentrations, milligrams per liter | | | |
| Total phosphorus | 0.72 | 0.76 | 0.68 | 0.75 |
| Ortho-phosphate | .53 | .49 | .33 | .49 |
| Total Kjeldahl nitrogen | 2.45 | 3.18 | 2.29 | 2.16 |
| Ammonia nitrogen | .53 | .79 | .5 | .53 |
| Total suspended solids | 7.7 | 21.0 | 25.2 | 20.2 |
| Volatile suspended solids | 2.6 | 5.1 | 4.0 | 5.5 |
| Dissolved oxygen | NA | 7.7 | 8.5 | 7.0 |

NA = Not available.
Sources: (21-24)

the monitoring period. Computer modeling allows manipulation of the conditions so that the effect of contracted BMP's on water quality can be analyzed.

## THE AGRICULTURAL NONPOINT SOURCE POLLUTION MODEL

Ever since scientists and policymakers recognized nonpoint source pollution as a significant and growing problem in the United States, they have sought answers to several difficult questions. There are physical questions of how to measure and minimize nonpoint pollution, and there are also economic and political questions of how to distribute limited funds to optimally reduce nonpoint pollution. Several mathematical models relating to nonpoint pollution have been developed to help identify answers to these questions.

The major pollutants from agricultural land that contribute to nonpoint pollution are sediment, plant nutrients such as P and N, and pesticides. Sediment is the greatest by volume and acts as a transport for other pollutants. The sediment soil particles adsorb plant nutrients and pesticides, which later may be transported as the sediment is detached by runoff (31). Consequently, estimating soil loss from farmland is a major objective of any nonpoint pollution model.

One of the first models to predict s il loss was the Universal Soil Loss Equation (USLE), which was developed in 1958 (30). The USLE estimates the average annual soil loss and, in doing so, considers the effect it has on land management practices. It is a simple model and is widely used by the Soil Conservation Service (SCS), particularly to identify alternatives for erosion control, but it has several limitations. The USLE predicts average annual soil losses, but nonpoint source pollution is more realistically characterized by intermittent discharges caused by storms. Spring storms may produce most of the nonpoint source pollutants released during the year. Other USLE limitations are that it can be used only in small areas, it does not estimate nutrient losses, and it does not provide "adequate estimates of pollutants reaching a stream or lake" (8).

The amount of pollutants reaching water resources depends on several factors that need to be incorporated into a nonpoint pollution model. These factors include the intensity and duration of the storm, soil types, land slope, watershed shape and size, and other physical characteristics. Other factors that also play an important role are farm management decisions, such as land use, manure storage, and the timing and quantity of manure, fertilizer, and pesticide applications.

Experience has shown us that a significant percentage of the pollutants entering water resources comes from limited portions of a watershed (14). Therefore, another goal of water quality models is to identify where improvements are needed within a watershed. A water quality model should project the amounts of pollutants entering surface or groundwater, trace the likely movement of pollutants within the waterways, indicate the level of soluble or plant-available nutrients, and help to identify where improved management practices are most needed.

The Minnesota Pollution Control Agency, the Minnesota Soil and Water Conservation Board, SCS, and the Agricultural Research Service (ARS) developed two integrated watershed models, which they use to analyze runoff quality from agricultural watersheds. These two models are AGNPS I and AGNPS II. The AGNPS

models are composed of sequential components that describe physical and chemical transport processes. The models simulate the flow and transport of sediment, N, P, and COD within a watershed and at the watershed's outlet for a single storm. This type of model has several applications: 1) it can be used to compare the performance of different watersheds experiencing the same type of event; 2) the performance of one watershed can be compared with preset standards of performance; 3) the performance of one watershed is evaluated before and after implementing BMP's; and 4) the areas within a watershed that are causing pollution are identified and targeted.

AGNPS I and II are mathematically identical; however, they require different computer hardware and software and differ in computing capacity. AGNPS I is designed to be used on either a personal or mainframe computer for watersheds of 500-23,000 acres, while AGNPS II is designed to be used with a programmable calculator for watersheds of 2.5-500 acres. Because the Jewett Brook watershed is approximately 3,436 acres, AGNPS I was used to analyze the effects of BMP's.

## Model Structure

The Jewett Brook watershed was initially divided into 10-acre cells. These cells were the basic unit for which data were collected and later calculated. The equations in the model simulate the hydrologic, erosion, sediment transport, chemical transport, and point source discharge processes (37).

Hydrology equations are used to calculate the runoff volume and peak flow rate. Runoff volume, which depends on rainfall, land use, soil type, and the hydrologic soil condition, is estimated with the SCS curve number method (19). The procedure from the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model estimates the peak runoff rate for each cell (13). This rate is a function of drainage area, channel slope runoff volume, and the watershed length-width ratio.

The upland erosion for a single storm is calculated from a modified form of the USLE. Soil loss is a function of total storm kinetic energy and maximum 30-minute intensity, soil erodibility, topography, plant cover, land management, and slope shape within the cell. Sediment is deposited or transported through the watershed from cell to cell in the model. The basic routing equation estimates how sediment travels through the watershed. In this equation, sediment discharge at the downstream end of a channel is a function of sediment discharge into the upstream end of the channel reach, lateral sediment inflow rate, downstream distance, reach length, channel width, and deposition rate. The model estimates the transport of N, P, and COD through the watershed using modified versions of the CREAMS model (11) and the feedlot evaluation model (35). As previously mentioned, N and P are major contributors to surface water eutrophication. COD measures the amount of oxygen required to oxidize organic and inorganic compounds in water (37). COD is used instead of biochemical oxygen demand (BOD) because "the analysis for BOD is more complex and time consuming and, as a result, less data are available on BOD concentrations..." (35). Results from several studies suggest that feedlot runoff, COD, and BOD are correlated with a ratio of approximately 4.5 to 1 (35).

N and P in runoff are divided into soluble and adsorbed phases in the model. The soluble phase represents the level of nutrients dissolved in runoff waters. The level of soluble nutrients in runoff depends on three factors: 1) the mean concentration of soluble N or P at the soil surface during a storm, 2) the extraction coefficient of N and P for movement into runoff, and 3) the

level of total runoff. The adsorbed phase represents the N and P transported by sediment and is also dependent on three factors: 1) the N and P content in the surface soil, 2) sediment yield, and 3) soil texture (37).

COD is assumed to be soluble and to accumulate without any losses in the AGNPS models. COD concentrations for each cell are determined from background concentrations of COD found in the literature. The estimated levels of COD in runoff from feedlots are based on runoff volume and the average COD concentrations in that volume (37).

Animal feedlots and barnyards are considered point sources of pollution in the AGNPS models. The feedlot pollution model estimates the contributions of N, P, and COD from the barnyards at both the barnyard edge and the receiving body of water (35). Sediment from gully, streambank, and overland erosion is considered the transport phase of the model (37).

Impoundments, gullies, and eroded streambanks were not modeled in this report. Relationships from the CREAMS model describe sediment and runoff routing through impoundments such as terraces (37).

## Data Requirements

RCWP in conjunction with the University of Vermont and SCS conducted yearly surveys of farms in the Jewett Brook watershed during 1982-86. These surveys contain detailed land use information for 96 percent of the Jewett Brook watershed. The land use practices for the remaining 4 percent were estimated from an SCS aerial map of the watershed.

The SCS office in Winooski, VT, supplied farm surveys that focused on before and after RCWP conditions. Additional input data were based on information available in three handbooks: Predicting Rainfall Erosion Losses, AH-537 (32); An Evaluation System to Rate Feedlot Pollution Potential, ARM-NC-17 (35); AGNPS I, A Large Watershed Analysis Tool, A Guide to Model Users (37).

The SCS farm surveys indicated before and after RCWP farm management conditions in the Jewett Brook watershed. Farms in the Jewett Brook watershed had not implemented many BMP's before RCWP. Animal waste was spread daily on nearly all cropland in the watershed and runoff from barnyards was allowed to enter surface waters. When manure is spread daily, it generally remains on the soil surface for long periods of time and can easily contribute to runoff pollution. In contrast, manure that is stored during the fall and winter and applied to fields shortly before plowing is less likely to contribute to nutrient runoff. Also, more N is available to plants due to decreased N volatilization when manure is stored and later incorporated in the soil.

As a result of RCWP cost-sharing funds, 13 of 18 barnyards in the Jewett Brook watershed were improved. Farmers managing 77 percent of the farmland in the watershed installed animal-waste storage structures. Detailed data for these farms are available for 1982-85. Several BMP's were implemented before or after 1982-85. To analyze the accomplishments of RCWP, we adjusted data for these farms to demonstrate before and after RCWP conditions.

To show before RCWP conditions for farms with BMP's implemented by 1982, data were adjusted to show the effects of spreading manure daily, and barnyard data were adjusted to simulate their unimproved state. Most RCWP farmers have manure to spread throughout the summer and fall in addition to their stored

manure, but all that we will attempt to model is the effectiveness of the nutrient management practices for a storm before and after spring applications of manure and fertilizer. To show after-RCWP conditions to farmers planning to implement BMP's with RCWP funding, the data were adjusted to show the effects of applying animal waste, stored for 6 months, to cornland in May and plowing it under within 2 days. A storm was modeled in March to show the control of nutrient runoff from barnyards and fields prior to manure application. Also, barnyards were modeled to show the effects of the planned improvements.

We divided the Jewett Brook watershed into 328 10-acre cells for this study. Because AGNPS I is limited to 300 cells, the Jewett Brook watershed was divided into two subwatersheds, one whose endpoint was 800 feet from the Jewett Brook watershed outlet. The watershed, as modeled, accounts for 3,280 acres. The acreage was modeled on the basis of earlier data and maps that measured the watershed acreage at 3,293 acres (21). This 13-acre difference is accounted for by cells on the boundary of the watershed having less than 5 acres, which were not included. This compares to 3,436 acres shown earlier as the total acreage for the Jewett Brook watershed (24). Very flat terrain along the watershed boundaries made acreage estimation difficult, and it is reported differently in the various St. Alban's Bay annual reports. The discrepancy in watershed size is not very significant for our purpose of comparing the effectiveness of management practices. The parameters of the AGNPS model and the applicable assumptions in this research are listed in appendix B.

## RESULTS FOR THE JEWETT BROOK WATERSHED

The AGNPS model estimates the losses of sediment, nutrients, and COD in runoff for each cell, feedlot, and watershed outlet for the time period and design storm of the operator's choice. The same 25-year design storm was applied to conditions in the Jewett Brook watershed for four different time periods: mid-March and mid-June 1982 (before RCWP) and mid-March and mid-June 1985 (after RCWP). We chose a 25-year storm to estimate the runoff and its constituents resulting from a severe storm. A 25-year storm reflects a rainfall intensity and amount that occurs only once every 25 years. Since the model is used to compare the relative changes in the watershed over a certain time period, any design storm may be chosen as long as it is held constant for all time periods. We later applied a 10-year design storm to the June 1985 data set to investigate the effects of less rainfall and intensity on watershed pollutant loadings and concentrations. Each storm event is independent of other storms and does not affect the results of other storm events. March and June storms were selected to analyze the effects of RCWP management practices both before and after nutrient applications normally made in April and May.

The results presented in this report show an overall decrease in the nutrients in runoff from the Jewett Brook watershed and support the notion that implementing nutrient management BMP's can improve the quality of runoff water. The results from the AGNPS model differ somewhat from the actual water quality data presented in table 1 for several reasons: (1) AGNPS estimates runoff from a single storm, while the reported data are presented as the means of monthly averages for a given year; (2) the data used in the AGNPS model were adjusted to show before and after RCWP conditions, so more improvements are accounted for in the AGNPS estimates of nutrients in runoff (such as the 1985 storms were modeled on the assumption that all BMP's were already implemented); and (3) existing buffer areas that act as nutrient traps may be releasing nutrients for

a long period of time, resulting in a delayed water-quality response to BMP implementation (as opposed to AGNPS estimates of steady-state water quality).

## Criteria for Analyzing Nutrient Levels

The RCWP was initiated in St. Albans Bay because a recently higher level of nutrients in the bay greatly increased the rate of eutrophication. The many variables associated with eutrophication have made government agencies reluctant to make rigid guidelines for P and N control. For example, Vermont's water-quality standards identify levels of dissolved oxygen, temperature, pH, turbidity, fecal coliform, color, and taste that should be allowed in different bodies of water, depending on their use (29), but they do not set criteria for P and N. Although State water quality criteria do not exist for P, N, and COD levels, studies indicate that eutrophication begins when total N exceeds 1-2 milligrams per liter and total P exceeds 0.025 milligram per liter (15). It has been suggested that to protect lakes from algal nuisances, the level of phosphate-P ($PO_4$-P) should not surpass 0.1 milligram per liter for streams discharging indirectly to lakes, and 0.05 milligram per liter for streams directly entering a lake (15). Jewett Brook enters a wetland before its waters reach St. Albans Bay, so the former figure is a more appropriate guideline for this study. EPA has determined that P is the nutrient that restricts algal growth in St. Albans Bay. Given this situation, the comparison between before and after RCWP nutrient levels in runoff focuses on the concentrations and loadings of P. Results are also reported for N and COD.

Our primary interest is with the soluble nutrients in runoff. The soluble form of P (soluble ortho-phosphate) is completely available for algal growth. Two other forms of P (soluble organic P and polyphosphate) are readily converted to ortho-phosphate (17). There are two important reasons for focusing on soluble P. First, nutrients in soluble form are available for algal assimilation. Nutrients that are in sediment are not readily available to plants, but they become available after microbial conversion of organic forms take place (10). Consequently, nutrients in sediment help maintain the soluble level of nutrients in water and, thereby, affect algal growth. Scientists estimate that approximately 20 percent of all P in sediment eventually is available to algae (7, 12). This suggests that approximately 20 percent of the values reported for total P in sediments becomes available to plants, provided the P concentrations are above 0.1 milligram per liter (7) as occurs in Jewett Brook (see table 1). Second, there is little erosion in the Jewett Brook watershed. An erosion rate of 3 tons per acre per year is considered a tolerable erosion rate for most soils in the Jewett Brook watershed. Based on USLE estimates, the average cropland erosion rate in the Jewett Brook watershed is about 1.4 tons per acre per year. In watersheds with low-erosion rates, a higher fraction of P is dissolved in water rather than adsorbed by sediment particles, especially under highly fertile conditions (16).

Three common forms of N are nitrate ($NO_3$), ammonium, and nitrite ($NO_2$). Two soluble forms, $NO_3$ and ammonium, enhance the eutrophication process because they are assimilated by aquatic organisms (10). N, more soluble than P, moves readily through the soil profile if it is not used by plants. N poses a greater groundwater contamination problem than P and is more concentrated in the first few feet of the soil horizon. Water quality standards in the United States limit the $NO_3$-N concentration in domestic water supply to under 10 milligrams per liter (28). $NO_2$ is a reduction product of $NO_3$. Since $NO_2$, the most toxic form of N, is 5 to 10 times more toxic than $NO_3$ (10), $NO_2$-N concentrations should not exceed 1.0 milligram per liter. At higher

concentrations, it can cause methemoglobinemia in infants, which impairs oxygen transport in the bloodstream and, in extreme cases, can cause death (15).

## N, P, and COD Levels at the Watershed Outlet

Table 2 shows (1) monitored changes in soluble P and N concentrations at the watershed outlet during the study period and (2) estimates of soluble nutrient concentrations from the AGNPS model. Because AGNPS estimates were determined for a 25-year storm at times of nutrient loadings and maximum runoff concentrations, the maximum reported levels of soluble P and N for each year are presented. Maximum soluble P and N concentrations vary considerably from year to year because they are sensitive to irregular storm events and the timing of water sampling (table 2). The monitoring data indicate that AGNPS estimates of soluble P and N concentrations probably are within a reasonable range, albeit higher in 1982 and lower in 1985 than tested samples. Our 1985 results are for the RCWP watershed as it will eventually be implemented; that is, we assumed all the contracted BMP's were already implemented in 1985 and that after-RCWP water quality conditions had been achieved. We cannot expect AGNPS to estimate the same concentrations as the monitored results. The purpose for using AGNPS is to compare the effectiveness of BMP's and RCWP, rather than predict the specific changes in water quality.

The AGNPS estimates indicate decreases in N and P losses and increases in COD at the watershed outlet after RCWP. Since there were changes other than BMP's (namely, a 32-percent increase in corn acreage from 1982-85), we begin by

Table 2--Soluble P and N: Annual maximum concentrations sampled at the outlet of the Jewett Brook watershed and AGNPS estimates for a 25-year design storm

| Item | 1982 1/ | 1983 | 1984 | 1985 |
|---|---|---|---|---|
| | Milligrams per liter | | | |
| Soluble P: | | | | |
| Maximum concentrations at the Jewett Brook monitoring station | 0.59 | 1.78 | 0.81 | 4.09 |
| AGNPS estimates for 25-year storm | 1.35 | NA | NA | .71 |
| Soluble N: | | | | |
| Maximum concentrations at the Jewett Brook monitoring station | 3.60 | 26.48 | 33.38 | 6.98 |
| AGNPS estimates a 25-year storm | 6.31 | NA | NA | 3.70 |

NA = Not available.
1/ Dec. 1981-Aug. 1982 (partial year).
Sources: (21-24).

discussing how this change affects water quality. The main difference between cornland and hayland is that corn is more erosive, has higher COD values, and receives higher organic and inorganic nutrient applications, which are eventually incorporated into the soil.

Although a larger amount of nutrients are applied, we hope that they are incorporated in the soil in a timely manner and are less available to runoff. Soluble nutrients in flat watersheds with little runoff may decrease from incorporation, while nutrients in sediment may increase from greater erosion (table 3). Both P and N follow similar patterns of change between 1982 (before RCWP) and 1985 (after RCWP). Soluble P and N stream loadings decreased by over 50 percent for March storms and by 22 and 20 percent, respectively, for June storms after RCWP (table 3). The large decrease in watershed losses of soluble P and N for March storms may be attributed to the reduction in winter manure applications and improved barnyards and buffer areas. The new animal waste storage structures (AWSS) enabled farmers to eliminate winter manure applications, while improved barnyards reduced the quantity of nutrients that reached surface water. Nutrient applications on cornland were usually incorporated, so that nutrient losses were less for the June storm than in March. The main reasons for N, P, and COD reductions were improved barnyards, increased fertilizer and manure incorporation, and less manure spreading on frozen and snow-covered ground.

Table 3--Phosphorus, nitrogen, and chemical oxygen demand concentrations at the Jewett Brook watershed outlet, 25-year storm

| Water quality parameters | Unit 1/ | March | | | June | | |
|---|---|---|---|---|---|---|---|
| | | 1982 | 1985 | Change | 1982 | 1985 | Change |
| | | | | Percent | | | Percent |
| Total P in sediment | Lbs/acre | 0.37 | 0.45 | 22 | 0.37 | 0.45 | 22 |
| Total soluble P in runoff | Lbs/acre | .56 | .24 | -57 | .37 | .29 | -21 |
| Total P loadings | Lbs/acre | .93 | .69 | -26 | .74 | .74 | 0 |
| Soluble P concentration in runoff | Mg/liter | 1.35 | .55 | -59 | .93 | .71 | -24 |
| Total N in sediment | Lbs/acre | .75 | .90 | 20 | .75 | .91 | 21 |
| Total soluble N in runoff | Lbs/acre | 2.65 | 1.28 | -52 | 1.87 | 1.50 | -20 |
| Total N loadings | Lbs/acre | 3.40 | 2.18 | -36 | 2.62 | 2.41 | -8 |
| Soluble N concentration in runoff | Mg/liter | 6.31 | 2.84 | -55 | 4.77 | 3.70 | -22 |
| Total soluble COD | Lbs/acre | 7.83 | 32.13 | 15 | 28.85 | 35.24 | 22 |
| Soluble COD concentration in runoff | Mg/liter | 66.94 | 71.20 | 6 | 73.60 | 87.20 | + 18 |

1/ Losses presented are the average losses per acre for the watershed. Total watershed losses can be calculated by taking the product of the watershed area, 3,280 acres, and the average loss per acre of each pollutant.

Total P and N loadings in sediment (pounds per acre) at the watershed outlet increased by approximately 22 and 20 percent, respectively, for a March storm (table 3). This increase was probably affected by the increase in corn acreage in the watershed during the same time period. The higher nutrient applications and erosion rates on cornland resulted in greater sediment-associated nutrient losses. These two factors contributed to overall higher nutrient loadings. Approximately 20 percent of P in sediment is available for algal growth, but it is less available than soluble P in runoff (table 3).

The soluble concentrations of P and N in monitored runoff are much greater than the minimum levels necessary for algal growth (table 2). This improvement, resulting from RCWP, is suggested by the decrease in concentrations. Soluble P and N decreased by 59 and 55 percent for a March storm (table 3). This decrease was somewhat affected by the greater runoff in 1985 (due to increased corn acreage), which diluted the nutrient concentrations. Most of the reduction, however, was from a decrease in soluble P and N loads, resulting from improved animal-waste management. Together, these two factors resulted in a substantial decrease in soluble nutrient concentrations. For the June storm, the concentrations of soluble P and N decreased by 24 and 22 percent, respectively (table 3).

Two COD values were computed by AGNPS at the watershed outlet. Total soluble COD load and concentration increased for March and June storms from 1982 to 1985. These increases range from 6 percent to 24 percent (table 3). The increase in corn acreage may have caused this increase, given that the COD value for cornland is 8.5 times higher than the COD value for hayland (37).

## Effects of Barnyard Improvements

There were 18 barnyards operated by 15 farmers within the Jewett Brook watershed in 1982. Some barnyards were combined through RCWP so that by 1985 15 watershed barnyards remained. All but one farmer participating in RCWP made some type of barnyard improvement (table 4). This farmer's contract was modified at the end of 1986, after completion of the study, to include barnyard improvements as well. The improvements focused on decreasing the tributary area draining into the barnyard; paving the barnyard, regularly scraping the manure, and storing manure in an AWSS; increasing the vegetative cover or the size of the buffer areas; and in more recent plans, diverting all runoff from the barnyard to an AWSS.

Some criterion is needed to identify problem barnyards. COD and BOD are lumped parameters that appear to be representative of most potential pollutants in barnyard runoff, and thus, can be used as a criterion for pollution potential. Minnesota established State standards for the level of BOD in feedlot runoff. According to the standards, a feedlot is considered a potential pollution hazard if BOD surpasses 25 milligrams per liter (35).

Because the ratio of COD to BOD is approximately 4.5 to 1 in northern States, COD concentration is limited to 112 milligrams per liter (35). Using this criterion for the Jewett Brook watershed, only 5 of the 18 barnyards in the watershed were not potential pollution hazards before RCWP in 1982 (table 4). Three of these 5 received RCWP cost-share funds for barnyard improvements.

The barnyard improvements led to a decrease in the soluble COD concentration and mass, except for barnyards 4 and 18 (table 5). Barnyard 4 was greatly reduced in size, and its tributary areas were eliminated. This caused COD

concentrations to increase by 6 percent, and COD mass to decrease by 74 percent. Animal usage in barnyard 18 increased between 1982 and 1985.

Although soluble COD concentrations in runoff decreased by more than 40 percent in 7 of 10 improved barnyards, the soluble COD concentration was still above the 112 milligrams per liter criterion used by Minnesota. Improved barnyards do not meet this criterion unless runoff is completely diverted to the AWSS.

The first barnyards that were improved with RCWP cost-sharing funds reduced or eliminated the water entering them, but runoff from the barnyard drained into an improved buffer area. It appears that the improved buffer area has a greater impact on decreasing COD levels than does minimizing runoff from the tributary area. For example, the only major change in three barnyards was to improve the buffer area. This was done by a combination of efforts, including: 1) planting a permanent vegetative cover, 2) decreasing land slope, and 3) increasing the size of the buffer area. COD loads from these three barnyards decreased by 42, 48, and 63 percent (table 5). The changes in two other barnyards affected only the amount of runoff entering the barnyard from the tributary areas, accomplished by installing gutters along the barn roof or

Table 4--Barnyard changes before and after RCWP in the Jewett Brook watershed

| Modifications to barnyard | Barnyards | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| No potential pollution hazard before RCWP 1/ | | | | | | | | | | | X | X | X | | | X | | |
| No improvements | X | | X | | | | | | | | | X | | | X | | X | |
| Decrease or eliminate tributary areas | | | | X | X | | X | X | X | X | | | X | | | | | |
| No buffer area | | | | | | | | | | | | | | | | | | X |
| Improve buffer area | | X | | X | | | X | | | | X | | X | | | X | | |
| Divert runoff from barnyard | | | | | | X | | X | X | X | | | | X | | | | |
| Animal usage increased after RCWP | | X | | | | | | | | | | | | | | | | X |
| Decrease barnyard area | | | | X | | X | | | | | X | | | | | | | |

1/ A barnyard is considered a potential point source of pollution when COD concentrations in runoff are greater than 112 milligrams per liter for a 25-year storm.



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using some other means to divert water. One barnyard showed a decrease in COD concentration of 28 percent, while the other had an increase of 0.2 percent (table 5). This latter barnyard also had an increase in animal usage, which explains the reason for the slight increase in COD concentration. Improving the buffer area may have a greater impact on the quality of runoff, but it may not be cost effective. Such buffer areas may or may not prove effective when buffering ability is low during periods of frozen ground and high runoff.

To determine the impact improved barnyards can make on the watershed's overall water quality, the March 1982 data set was adjusted to show the effect of diverting runoff from all potentially hazardous barnyards (such as barnyards where COD concentrations in runoff exceed 112 milligrams per liter) in the watershed to AWSS's. Estimates of soluble P and N loads and concentrations at the watershed outlet decreased from 4 to 7 percent after RCWP, while P and N in sediment remained constant (table 6). These decreases in soluble nutrients are much less than those estimated to occur due to RCWP (see table 3), suggesting that barnyard improvements alone account for a small fraction of the nutrient reductions at the watershed outlet. This is because many nutrients in barnyard runoff are assimilated by the time they reach a stream, especially if the area downslope is pasture or hayland. N, P, and COD losses for cells (in the AGNPS model) with barnyards are usually just slightly higher than those of other cells.

Table 5--Chemical oxygen demand and phosphorus concentrations at barnyard discharge points, March 1982 and March 1985, from a 25-year storm

| Barnyards | COD concentration | | P concentration | | COD mass | | P mass | |
|---|---|---|---|---|---|---|---|---|
| | 1982 | 1985 | 1982 | 1985 | 1982 | 1985 | 1982 | 1985 |
| | Milligrams per liter | | | | Pounds | | | |
| 1 | 276.3 | 276.3 | 3.3 | 3.3 | 259.2 | 259.2 | 3.1 | 3.1 |
| 2 | 846.6 | 489.7 | 21.7 | 12.2 | 508.5 | 314.1 | 13.1 | 7.8 |
| 3 | 3,782.0 | 3,782.0 | 73.7 | 73.7 | 602.4 | 602.4 | 11.7 | 11.7 |
| 4 | 47.4 | 50.5 | 1.6 | 1.7 | 103.8 | 27.1 | 3.5 | .9 |
| 5 | 168.5 | 120.9 | 3.5 | 2.8 | 388.1 | 266.1 | 8.0 | 6.2 |
| 6 | 368.7 | 0 | 7.7 | 0 | 1,874.0 | 0 | 38.9 | 0 |
| 7 | 555.6 | 291.6 | 7.8 | 3.4 | 358.5 | 64.9 | 5.0 | .7 |
| 8 | 587.7 | 0 | 7.0 | 0 | 276.8 | 0 | 3.3 | 0 |
| 9 | 522.5 | 0 | 6.2 | 0 | 106.1 | 0 | 1.3 | 0 |
| 10 | 1,135.0 | 0 | 11.8 | 0 | 508.8 | 0 | 5.3 | 0 |
| 11 | 572.4 | 298.9 | 6.0 | 3.8 | 217.4 | 101.9 | 2.3 | 1.3 |
| 12 | 39.8 | 39.8 | 1.1 | 1.1 | 98.8 | 98.8 | 2.8 | 2.8 |
| 13 | 64.4 | 52.2 | 1.6 | 1.7 | 53.4 | 20.5 | 1.4 | .7 |
| 14 | 45.7 | 0 | 1.5 | 0 | 115.7 | 0 | 3.9 | 0 |
| 15 | 1,383.0 | 1,383.0 | 29.9 | 32.2 | 136.1 | 136.1 | 2.9 | 3.2 |
| 16 | 2,116.0 | 785.8 | 22.6 | 9.6 | 1,157.0 | 484.1 | 12.4 | 5.9 |
| 17 | 36.7 | 36.7 | 1.2 | 1.2 | 33.1 | 33.1 | 1.1 | 1.1 |
| 18 | 248.6 | 249.2 | 2.7 | 2.7 | 186.7 | 198.6 | 2.0 | 2.2 |

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## Effects of Nutrient Management

The effects of nutrient management are most apparent in the results presented for March 1982 and 1985. This is due mainly to the change in manure applications, which before RCWP were usually applied to frozen or snow-covered soil during the late fall and winter. These manure applications were highly susceptible to runoff during March storms because manure was not incorporated in the soil until late spring. Because the AWSS eliminated the need for late fall and winter applications of manure, the nutrient losses were greatly reduced during the March 1985 storm (table 3). The effect of nutrient management is substantial but less for the June storms. Nutrient applications for June 1985 were higher than June 1982, because more nutrients were used from the stored manure, and the increased cornland required greater nutrient applications. More land was plowed in 1985, thus reducing nutrient availability for runoff.

Before RCWP, all farmers in the Jewett Brook watershed, with the exception of one, spread manure on a daily basis throughout the fall and winter. After RCWP, 15 farmers had signed contracts to install AWSS's using RCWP cost-sharing funds. Eleven of these farmers and one noncontract farmer applied manure in the spring and fall, and they incorporated the manure shortly after its application on cornland to minimize nutrient runoff. These farmers managed approximately 70 percent of the acreage in the watershed. The other four contract farmers applied manure during the late fall without incorporating it. Three noncontract farmers continued to spread manure daily after RCWP.

Table 6--Effect of diverting runoff from potentially hazardous barnyards in the Jewett Brook watershed according to AGNPS estimates 1/

| Parameters | Unit | March 1982 | March 1985 2/ | Change |
|---|---|---|---|---|
| | | | | Percent |
| Total P in sediment | Lbs/acre | 0.37 | 0.37 | 0 |
| Total soluble P in runoff | Lbs/acre | .56 | .53 | -5 |
| Total P loadings | Lbs/acre | .93 | .90 | -3 |
| Soluble P concentration in runoff | Mg/liter | 1.35 | 1.26 | -7 |
| Total N in sediment | Lbs/acre | .75 | .75 | 0 |
| Total soluble N in runoff | Lbs/acre | 2.65 | 2.55 | -4 |
| Total N loadings | Lbs/acre | 3.40 | 3.30 | -3 |
| Soluble N concentration in runoff | Mg/liter | 6.31 | 6.09 | -3 |

1/ A potentially hazardous barnyard is defined to be one that has COD runoff concentrations greater than 112 milligrams per liter (35). The only improvement made in the watershed was diverting runoff from potentially hazardous barnyards.

2/ Losses presented are the average losses per acre for the watershed. Total watershed loadings can be calculated by taking the product of the watershed area, 3,280 acres, and the average loss of nutrients per acre.

Although some farmers continued with late fall and winter applications of manure, an overall decline in nutrient loadings is estimated to occur at the watershed outlet. This decline can be attributed to improved animal-waste management and barnyards. For example, comparing nutrients in runoff at the cell outlet for a 25-year storm in March 1982 and 1985 (see table 3), there was a 57-percent decrease in the soluble P load and a 52-percent decrease in the soluble N load, while soluble P and N concentrations decreased by 59 and 55 percent, respectively. Available P in sediment (about 20 percent) increased by approximately 22 percent, but the level of soluble P was about eight times greater than available sediment P in March 1982 and three times greater in March 1985. Therefore, the increase in total P in sediment is outweighed considerably by the decline in soluble P.

Comparing the results for each cell in the AGNPS model also supports the conclusion that improved animal-waste management reduced nutrient runoff. In March 1982, 68 cells had P concentrations of at least 2 milligrams per liter, yet by March 1985 only 14 cells had concentrations exceeding that level. To eliminate the effect of any change in land use, this same analysis was applied to cells where the predominant land use did not change from 1982 to 1985. There were 48 cells in 1982 that had P concentrations of at least 2 milligrams per liter, while there were only 12 in 1985.

There were two farms at the watershed outlet, accounting for 10 percent of the acreage in the watershed, where manure was applied in the late fall or winter in both 1982 and 1985. One farmer did not have a contract. The other participated in RCWP but applied very large amounts of stored manure during late fall of 1985. While this activity does not necessarily represent after-RCWP conditions accurately, we modeled what actually was done by these farmers in 1985. Then to show the actual effects of RCWP as it will be implemented eventually, this contract farm was modeled as it should be managed after full BMP implementation. Also, the noncontract farm was modeled as conforming to nutrient-management provisions established under RCWP.

Pollutants from farms located at the watershed outlet have less chance of being deposited or assimilated before exiting the watershed. This implies that the quality of watershed runoff from these farms has more impact than runoff from farms located farther from the watershed outlet. Given this situation, we expect that implementing BMP's on farms located at the outlet could significantly improve the quality of water leaving the Jewett Brook watershed.

All manure was applied on the contract farm at the watershed outlet in late October or early November 1985. These applications were heavy (25 plus tons per acre on cornland) and not incorporated. The data set for March 1985 was adjusted to show the impact of no nutrient applications during October-March on cornland for this farm. This reduced soil nutrient levels at the time of the March 1985 storm. The results calculated by AGNPS show large decreases in soluble P and N loads and concentrations, while total P and N in sediment remain constant (table 7). Note that these changes can be obtained without additional RCWP funds, but farmers must comply with the contract guidelines.

The March 1985 data set was also adjusted to show water quality improvements if the noncontract farmer at the watershed outlet also eliminated manure applications during October-March. The results show further decreases in the soluble P and N loadings and concentrations (table 7). Again, sediment-associated N losses remain constant.

One last possibility was investigated for controlling barnyard runoff: the cost of completely eliminating runoff from the barnyards. Eliminating runoff involves removing the drainage grates from the cemented and curbed barnyards and diverting all the barnyard waste and runoff into the storage structures. For a medium-sized farm with a herd of 58 cows, the cost of installing an

Table 7--Effects of nutrient management for the farms at the bottom of the watershed on water quality at the watershed outlet, according to AGNPS estimates 1/

| Parameters | Unit | March runoff 2/ | | | Modified March 1985 runoff (no nutrients applied from October-March) 2/ | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1982 | 1985 | Change from 1982 | Farm 1 | Change from 1982 | Farms 1 and 2 | Change from 1982 |
| | | | | Percent | | Percent | | Percent |
| Total P in sediment | Lbs/acre | 0.37 | 0.45 | 22 | 0.45 | 22 | 0.45 | 22 |
| Total soluble runoff P | Lbs/acre | .56 | .24 | -57 | .14 | -75 | .10 | -82 |
| Total P loadings | Lbs/acre | .93 | .69 | -26 | .59 | -37 | .55 | -41 |
| Soluble P concentration in runoff | Mg/liter | 1.35 | .55 | -59 | .31 | -77 | .23 | -83 |
| Total N in sediment | Lbs/acre | .75 | .90 | 20 | .90 | 20 | .90 | 20 |
| Total soluble runoff N | Lbs/acre | 2.65 | 1.28 | -52 | .85 | -68 | .73 | -72 |
| Total N loadings | Lbs/acre | 3.40 | 2.18 | -36 | 1.75 | -49 | 1.63 | -52 |
| Soluble N concentration in runoff | Mg/liter | 6.31 | 2.84 | -55 | 1.85 | -71 | 1.00 | -84 |

Farm 1 = contract farm at watershed outlet.
Farm 2 = noncontract farm at watershed outlet.

1/ Adjustment to data for March 1985 shows potential effects if farms 1 and 2 had animal-waste management practices.

2/ Losses presented are the average losses per acre for the watershed. Total watershed nutrient loadings can be calculated by taking the product of the watershed area, 3,280 acres, and the average loss of nutrients per acre.

animal-waste storage structure averages $18,624 and $53,654 for an earthen-pit or aboveground AWSS, respectively (33, 1985 dollars). A 15-percent increase in storage capacity is necessary for this size operation. Such an expansion is inexpensive for an earthen pit and moderately expensive for a concrete or steel structure. More liquid would have to be removed from storage and applied to cropland, which is an added expense. These additional costs would be partially offset by the nutrients available in the barnyard waste. Not all barnyards are located where wastes can be diverted to a storage structure.

## Cost of Abatement Activities

The results presented indicate there was a decrease in total P between March 1982 and March 1985 (before and after RCWP). The question now remains, what are the relative costs of these various BMP's or abatement activities? Our investigation focuses on soluble P, which is the primary cause of algal blooms in St. Albans Bay. AGNPS estimates soluble P both produced within each cell and at the watershed outlet. Since soluble P at the cell outlet includes the input from upland cells, our calculations are based on soluble P generated within each cell. The pounds of soluble P per farm is the sum of soluble P within each cell included in the farm's acreage. Total loadings of soluble P per farm are divided by adjusted abatement costs to determine the relative abatement costs.

To calculate the cost per reduction in soluble P from participating RCWP farms, the total cost was estimated from information provided by SCS (Winooski, VT). The SCS data included the Government's cost share of each farmer's contract, 75 percent of the total cost of the AWSS and most barnyard improvements. Since the farmer incurs 100 percent of the cost of some relatively inexpensive BMP's (such as cropland protection systems), the total cost we present is slightly less than the actual total cost. Total cost was further adjusted to account for the percentage of farm acreage contained within the watershed. The fraction of the total cost directly corresponds to the percentage of the farm's acreage inside the watershed (table 8).

There did not appear to be a strong correlation between the cost per reduction in P and the type of AWSS. The AWSS's account for the greatest portion of the total cost and range from $11,966-$51,434 (1985 dollars) in the Jewett Brook watershed. Aboveground structures are more expensive and tend to be used in areas where the site is inappropriate for an earthen pit. The cost also increases with storage capacity and varies with the physical nature of the site. More expensive manure management systems are found to have high, medium, and low relative abatement costs, suggesting there is not a significant relationship between total cost and relative abatement cost (see table 8, farms 4,9, and 15).

The cost of soluble P reduction appears to be related to the initial soluble P loss per acre (table 8). Theory suggests that marginal abatement costs increase as the level of pollution is reduced, implying that it is more efficient to spend funds where high levels of pollution exist. This appears to be the situation in the Jewett Brook watershed. The cost for reducing the first few pounds of P is much lower than that for further P reductions. Farms with higher losses of soluble P before RCWP are the farms with the lowest relative abatement costs.

The relative abatement costs for P from participating Jewett Brook farms vary widely (table 8). There is a twentyfold difference in the relative costs per

pound of P reduction between farm 1 and farm 15. The costs in table 8 are used only for ranking the farms' cost effectiveness. The relative abatement costs do not consider the farms' locations. Ideally, location should be incorporated to reflect the positive relationship between water quality damages and proximity of nonpoint pollution sources to waterways and watershed outlets.

The same analysis is less conclusive when applied to barnyards although the cost per pound of P abatement appears to be more related to the initial P levels than the type of barnyard improvement (table 9). The barnyard with the least abatement cost, which simply involved reducing the tributary area entering the barnyard, had the highest level of soluble P in runoff before RCWP. Barnyards with the highest relative abatement costs were those with the lowest P losses in March 1982. These findings support our proposition that there is a negative correlation between initial levels of P loss and relative abatement cost; however, exceptions exist. Barnyards 2 and 3 had high soluble P losses in March 1982 and high relative abatement costs, due partly to an increased use by animals during 1982-85.

Table 8--Relative abatement costs of reducing soluble P losses in field runoff on farms implementing BMP's, 25-year design storm in March

| Farms' cost per pound ranking 1/ | Total reduction in soluble P loss, 1982-85 | Average soluble P loss per acre, March 1982 | BMP's | |
|---|---|---|---|---|
| | | | Total cost 2/ | Adjusted cost 3/ |
| | Pounds | | Dollars | |
| 1 | 265.9 | 162 | 40,239 | 22,533 |
| 2 | 46.0 | 22 | 28,595 | 4,003 |
| 3 | 156.0 | 101 | 32,946 | 26,027 |
| 4 | 305.0 | 115 | 65,004 | 65,004 |
| 5 | 51.9 | 56 | 23,480 | 11,740 |
| 6 | 60.8 | 49 | 24,459 | 24,459 |
| 7 | 50.7 | 48 | 25,265 | 25,265 |
| 8 | 53.3 | 35 | 29,912 | 28,716 |
| 9 | 61.2 | 37 | 60,060 | 39,101 |
| 10 | 5.9 | 42 | 24,885 | 5,225 |
| 11 | 52.7 | 35 | 39,356 | 39,356 |
| 12 | 17.5 | 19 | 16,961 | 16,961 |
| 13 | 24.6 | 27 | 27,424 | 27,424 |
| 14 | 21.6 | 22 | 37,660 | 37,660 |
| 15 | 35.2 | 30 | 61,869 | 61,869 |

1/ The farms are ranked according to their cost per pound of soluble P saved, from the least cost to the greatest. Because this is done for a single storm event, the actual cost per pound has no meaning except for a relative comparison of the farms' nutrient runoff control costs.

2/ Expressed in 1985 dollars.

3/ Cost was modified to reflect the percentage of contracted land that was within the Jewett Brook watershed.

Since complete diversion of runoff is the most effective means of limiting nutrient runoff, it is interesting to compare the costs of complete diversion systems with other barnyard improvements such as improved buffer strips. Barnyards with completely diverted runoff to the AWSS must have increased storage capacity, which increases the cost of a storage structure. The three farms that had complete diversion systems installed have higher relative abatement costs than two other farms and lower costs than three. This suggests that complete diversion systems may be cost effective if the barnyard is a significant pollution hazard.

These results emphasize the importance of estimating the level of pollution coming from a farm before allocating funds for BMP implementation. Allocating Government funds to farms with higher pollution levels takes advantage of the lower marginal abatement costs.

It was desirable to make an estimate of the range in annual costs for total P reduction in Jewett Brook. If total P in sediment and soluble P in runoff are combined for the design storm in March, the total watershed loading of P declined from 3,050 pounds in 1982 to 2,265 pounds in 1985. The runoff from

Table 9--Relative abatement costs of barnyard improvements for a 25-year design storm

| Barnyard ranking and number 1/ | P loss in March | | Cost of barnyard improvements 2/ |
|---|---|---|---|
| | 1982 | 1985 | |
| | ---------Pounds------- | | Dollars |
| 5 and 6 3/ | 46.88 | 6.2 | 5,589 |
| 6 | 12.38 | 5.8 | 2,680 |
| 14 | 3.86 | 0 | 4,995 |
| 8 and 9 3/ | 4.54 | 0 | 8,466 |
| 7 | 5.02 | .7 | 8,110 |
| 4 | 3.46 | .9 | 4,879 |
| 10 | 5.31 | 0 | 10,548 |
| 2 and 3 3/ | 24.78 | 19.6 | 11,637 |
| | 1.36 | .7 | 4,144 |
| 18 4/ | 2.70 | 2.7 | 8,434 |
| 11 | 2.27 | 1.3 | 11,468 |

Note: Barnyards without improvements are not included.

1/ The barnyards are ranked according to the cost per pound of soluble P saved, from the least cost to the greatest. The barnyard numbers correspond to the numbering system used in tables 4 and 5.
2/ Expressed in 1985 dollars.
3/ Two barnyards on one farmstead.
4/ The barnyard had an increase in animal usage.

this storm was approximately 2 inches, or about a tenth of the average annual runoff. If the nutrient concentration in runoff throughout the year was constant before and after RCWP, multiplying the difference of P loadings between 1982 and 1985 by 10 yields a savings of 7,850 pounds of total P. The average annual nutrient concentrations probably would not be as great as they are for this spring storm. By simply multiplying this difference, the actual P savings in the watershed will likely be overestimated. Thus, we are making some optimistic assumptions about P control. These assumptions are for illustrative purposes only to estimate in rough terms the cost of agricultural nonpoint pollution control in the Jewett Brook watershed.

The adjusted costs of BMP's in table 9 were discounted for 20 years at 7.88-percent interest to estimate average annual costs. These present values ranged from $404 per year (farm 2) to $6,243 per year (farm 15) . The cost per reduction in total P averaged $5.60 per pound. This compares favorably with urban sewage treatment costs (34). The range across farms would be annual costs of roughly $1-$36 per pound of total P reduction.

These estimates are crude, but they help to demonstrate the cost effectiveness of animal waste management and serve to place boundaries on the costs of runoff control. Sewage treatment plants in the RCWP watershed remove up to 90 percent or more of total P at an average cost of about $4 per pound (38). About 52 percent of the total P loading in the St. Albans Bay watershed was from the two wastewater treatment plants within its boundaries (23). Those plants were upgraded to remove P at a cost of $1.3 million. The cost to reduce agricultural nonpoint P runoff was about $1.6 million. Other agricultural pollutants were also controlled because of agricultural nonpoint pollution control. The removal efficiency of agricultural BMP's in Jewett Brook was estimated as a 26-percent reduction in P losses only (table 3). Agricultural BMP s appear reasonably cost effective compared with the concurrently implemented point source control when all pollutants are considered. Other pollution control programs should also consider controlling point sources as well as nonpoint sources since the marginal cost of abatement for wastewater treatment often is less than the marginal cost of abating nonpoint pollution.

## Changes in Sediment Yields

Sediment at the watershed outlet increases after RCWP (1985) by 27 percent for a March 25-year storm and 29 percent for a June 25-year storm. These increases in sediment delivery result from a 32-percent increase in corn acreage, which most likely is a cyclical high in the corn-hay rotation cycles of a number of RCWP farmers. We would not expect a substantial change in sediment yields if the cropland distribution had not changed during 1982-85. It is expected that average longrun sediment yields will decline after RCWP. Readers are reminded that 1985 does not fully represent post-RCWP land use, although the BMP's are assumed to be fully implemented as planned. Because erosion and sediment are not significant water quality problems in the Jewett Brook watershed, the BMP's that were implemented did not focus on soil erosion as much as they emphasized nutrient management.

## Effects of Storm Intensity

The June 1985 data set that was used to assess the effect of storm intensity was evaluated with a 10-year storm. The 25-year storm (discussed earlier) has 4 inches of precipitation in 24 hours and its storm energy-intensity value is

58, while a 10-year storm has 3.5 inches of precipitation and its storm energy-intensity value is 47 (26).

The nutrient loads declined from 7 to 20 percent by changing from a 25-year to a 10-year storm (table 10). N loadings appear slightly more sensitive to storm intensity than P loadings. A 10-year storm obviously leads to reduced runoff, and, in this example, the reduction in runoff resulted in higher soluble nutrient concentrations. Runoff concentrations increase by 13 percent for P, 16 percent for N, and 1 percent for COD. Sediment-associated P and N loadings were 18 and 20 percent less, respectively, for the 10-year storm versus the 25-year storm.

Water quality monitoring results generally show somewhat higher nutrient concentrations from greater runoff events (24). We conclude from the modeling

Table 10--AGNPS estimates of runoff quality at the watershed outlet with different storm intensities, June 1985 1/

| Parameters | Unit | 25-year design storm | 10-year design storm | Change |
|---|---|---|---|---|
| | | | | Percent |
| Total P in sediment | Lbs/acre | 0.45 | 0.37 | -18 |
| Total soluble P in runoff | Lbs/acre | .29 | .26 | -10 |
| Total P loadings | Lbs/acre | .74 | .63 | -15 |
| Soluble P concentration in runoff | Mg/liter | .71 | .80 | +13 |
| Total N in sediment | Lbs/acre | .91 | .73 | -20 |
| Total soluble N in runoff | Lbs/acre | 1.50 | 1.40 | -7 |
| Total N loadings | Lbs/acre | 2.41 | 2.13 | -12 |
| Soluble N concentration in runoff | Mg/liter | 3.70 | 4.30 | +16 |
| Total soluble COD | Lbs/acre | 35.24 | 28.16 | -20 |
| Soluble COD concentration in runoff | Mg/liter | 87.20 | 88.20 | +1 |

1/ Losses presented are average losses per acre for the watershed. Total watershed pollutant loadings can be calculated by taking the product of the watershed area, 3,280 acres, and the average pollutant loss per acre.

results, however, that greater storm intensity will generally increase the loadings but decrease the concentrations of soluble chemicals in the watershed. While this does not affect the relative comparisons that we made with the model, intuitively the greater dilution of a major runoff event would be expected to result in lower nutrient concentrations, as our estimates suggest. The overall effects on water quality in St. Albans Bay due to greater nutrient loadings from a more intense storm would depend on: (1) how much of a chemical load is delivered to the bay via the wetland, (2) the amount of time biologically available P and N remain in the bay, and (3) the nutrient quality of other waterways entering the bay. With the limited sediment problems and reduced chemical concentrations associated with very intense storms, it is difficult to determine if increased loadings pose a more serious pollution hazard in Jewett Brook than the relatively higher concentrations associated with a less intense storm.

## Long-Term Water Quality Improvement

The results indicate that water quality is affected by nutrient management, namely the timing and incorporation of animal waste and fertilizers. The long-term water quality and success of RCWP ultimately depend on the farmer as a nutrient manager. Because long-term water quality depends on the farmer as a nutrient manager, we need to assess the incentives the farmer has to comply with contract guidelines.

Linear programming results indicate that farmers' net incomes increase with an AWSS for medium- and large-size farms, provided that farmers install the cheaper earthen pit and there is Government cost sharing of 25 percent or more (34). Farmers' net incomes increase with either the above-ground structure or the earthern pit when the Government cost share is 75 percent. The timing of nutrient application is important. Manure should be incorporated soon after its application so that volatile nutrients are not lost, most nutrients are available to plants, and there is less need for chemical fertilizers. It is to the farmer's advantage to incorporate the manure immediately after application.

Animal waste is usually applied in the spring before planting. The gain from applying manure during very wet or late springs may be less than the opportunity cost of planting the crop as soon as possible and using chemical fertilizers. We could expect the farmer to apply the stored manure in the late summer or fall if there is sufficient storage capacity when spring weather conditions are unfavorable for field work. Since most AWSS's have storage capacity for 200 days, plus freeboard, spring applications that are delayed could cause waste overflow that could reduce water quality. Manure stored in areas subject to runoff until the fields are fallow and ready for applications could also reduce water quality.

Farmers seem to have an incentive to apply animal waste, according to contract guidelines, in years with favorable spring conditions. Fortunately, the incentive to maximize profits coincides with good nutrient management. When field conditions and timing are such that the opportunity cost of not planting immediately is greater than the gain from applying stored animal waste, water quality may be adversely affected. Monitoring nutrient applications under different spring scenarios could help determine conditions favorable to good nutrient management.

## IMPLICATIONS

Estimates from the AGNPS model indicate that BMP's implemented in the Jewett Brook watershed should reduce N, P, and COD in runoff, other things being equal. Although BMP's improve water quality, AGNPS results suggest that the nutrient levels in runoff are still above the minimum needed for algal growth. The 21-percent average reduction in soluble nutrient loadings and concentrations due to RCWP is encouraging. We can expect the marginal cost of additional abatement to increase as lower concentrations of P, N, and COD in runoff are reached. It may be uneconomical, therefore, to reduce nutrients to the minimum level needed for algal growth.

The AGNPS analysis was done for a 25-year storm. The implementation of RCWP was shown to improve water quality for both 10- and 25-year storms. We expect similar improvements for less severe storms. Another point regarding the change in water quality concerns water quality monitoring. Water quality probably will not improve immediately because of the slow release of nutrients trapped in compounds.

The results suggest that BMP's are more effective during certain periods of the year. For example, the AWSS has a more significant effect on water quality in March because manure is stored during the winter months and applied in the late spring before plowing. Concentrations of total N in Jewett Brook are greatest during February and should decline substantially as a result of manure storage practices. The reduction in stream nutrients is relatively smaller in June. Other BMP's, such as soil conservation practices, have more effect on runoff during periods of high runoff after seedbed preparation in the spring. The highest P concentrations are found in June stormflow and are not expected to decline as much as early spring nutrients. In other words, the effect of various BMP's on water quality will vary throughout the year. The person selecting the BMP's should consider the timing of runoff events and what specific water quality problems are to be addressed. Because there usually is substantial runoff from Jewett Brook resulting from winter thaws and spring rains (24), we expect that AWSS's will play a significant role in improving water quality if the manure is incorporated soon after its application. Other important BMP's include barnyard improvements and grass filter strips. These three animal waste management BMP's accounted for 97 percent of the cost-sharing funds spent during RCWP.

Water quality improvements depend on the farmer as a nutrient manager. Farmers may not have direct incentives to improve water quality, but they do have indirect incentives to improve water quality. We can expect water quality improvement in the long run if the gains from applying manure in the spring are greater than the costs. Conditions that are unfavorable for fieldwork in the spring could delay manure application until summer or fall, which, in turn, could lead to greater nutrient runoff problems. Farmers must devise a manure-spreading strategy that will assure good returns from the manure nutrients and minimize the risk of water pollution.

Many of this report's findings and conclusions on manure storage and handling systems are believed to be applicable for other regions. Results from the economic analysis of RCWP indicate that reducing nutrient losses from agricultural watersheds is expensive, hence the justification for cost sharing. Animal-waste storage structures, however, may actually improve net returns on Vermont dairies with a shortage of manure nutrients for crop production. Larger operations have been found to be more profitable after

manure storage systems were implemented, both by RCWP and previous economic analyses of northeastern dairies. Smaller marginal costs of P control have been correlated with larger operations.

This report highlights an important point with regard to protecting water quality. The location of a farm in a watershed and the relative magnitude of pollution among farms will both determine the cost per unit reduction in pollution. If a farm that is far from major receiving waters or has relatively little nutrient runoff is treated with BMP's, the cost of reducing pollution at the watershed outlet will be comparatively high. This is true whether it is a small or large farm. Reducing nutrient runoff inexpensively from a large dairy operation is not cost effective if the runoff is not reaching waterways. Funds should be targeted to significant pollution sources with higher delivery ratios to the water being protected.

This last point highlights a disadvantage of AGNPS. The model does not provide users with estimates of pollutant delivery from individual cells to the watershed outlet. It is, therefore, impossible to determine the effect of pollution from a particular barnyard, field, or farm on end-of-stream water quality. The user is limited to estimating delivery to the edge of a cell within the model. Some method of tying pollution from individual sources to downstream points in the watershed would allow still more effective targeting of pollution sources.

Other measures beyond manure and nutrient management to reduce nutrient losses--soil conservation BMP's, reduced livestock and crop production, manure export--could cause substantial reductions in farm income if not cost shared (5, 33). The costs to farmers were minimized in Jewett Brook because almost all the practices implemented in RCWP relate to animal waste management. Other studies have made similar conclusions, and it appears that storage systems represent the most economically viable way for farmers to control nutrient runoff. Soil conservation or reduced nutrient loadings may be necessary for pollution control in areas with higher erodibility and groundwater contamination or interflow problems. In nonerodible areas without groundwater concerns, better manure and fertilizer management should substantially reduce nutrient runoff and, thus, improve water quality.

## CONCLUSIONS

The purpose of this report was to evaluate the effects of nutrient management on water quality. Several objectives were addressed: (1) evaluating the effectiveness of animal waste management practices for improving water quality, (2) determining if the projected water quality improvements were accomplished cost effectively through RCWP, and (3) reporting findings on changes in farmers' net incomes from implementing BMP's with government cost sharing. These three issues were addressed simultaneously to give us insight to a methodology for planning future agricultural nonpoint pollution control projects.

The quality of each farm's and barnyard's runoff should be compared and each potential problem should be evaluated before funds are allocated. The marginal cost of abatement is higher for nonpoint sources with low initial nutrient runoff levels. To take advantage of lower marginal abatement costs and achieve maximum cost efficiency, the government should allocate funds to farms and barnyards that contribute most to the pollution problem. Since a farmer's

net income usually increases when an AWSS is installed with 75-percent cost sharing, there is an incentive for farmers to participate in cost-sharing programs whether or not their farm is the source of significant pollution. Participants should be carefully screened so that cost-sharing funds will be spent on farms or barnyards with significant pollution hazards.

Analysis with the AGNPS model illustrated the importance of farm location within the watershed. Farms located closer to streams and the watershed outlet offer greater potential water quality improvements with good nutrient management. The above findings imply that funds for cost-sharing programs should be allocated on the basis of farm location and initial contamination levels. Models such as AGNPS can significantly contribute to farm targeting by assessing the contribution of each field and farm to stream nutrient levels, although ideally the model should explicitly provide estimates of pollutant delivery from individual cells to the watershed outlet.

The linear programming model developed for the RCWP evaluation suggests that cost sharing may not always be needed or at least should be varied, depending on the type of AWSS needed to be installed and the farm size. Program planners and researchers may wish to explore, using a model such as AGNPS, more refined targeting methods and variable cost-sharing formulas according to changes in net farm income and water quality likely to result from desired BMP's.

An important finding of previous studies was confirmed here; reducing stream levels of nutrients through agricultural BMP's is relatively expensive. Agricultural watersheds typically receive large inputs of nutrients from manures and fertilizers and, therefore, have relatively high nutrient runoff concentrations compared with nonagricultural watersheds, regardless of farm management practices. However, the assimilative capacity of the environment, including uptake by crops, can remove from the aquatic environment up to 94 percent of the P applied to agricultural land in the RCWP watershed. This estimate is based on fertilization and nutrient loading data for St. Albans Bay (21). The removal efficiency of normal agricultural cropping activities rivals or exceeds that accomplished by most sewage treatment plants designed to remove P from water. Further reduction through BMP's follows the rule of increasing marginal abatement costs. For the Jewett Brook watershed, the annual costs of nonpoint P removal were estimated to range from $1 to $36 per pound of total P reduction. Young and Shortle (34) estimated urban sewage treatment costs for P removal were 29 percent below the costs of nonpoint control in the St. Albans Bay watershed. Animal waste management reduces losses of N, BOD, COD, solids, and other pollutants. Therefore, urban sewage treatment and nonpoint pollution control theoretically should be pursued only to the point where the marginal costs of point and nonpoint controls are comparable. The efficacy of pursuing such an alternative depends on such things as the relative contributions of point and nonpoint sources, availability of farm capital versus municipal capital, technical expertise and information, and other site-specific parameters that must be considered in every watershed.

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## APPENDIX I: IMPLEMENTATION OF BMP'S IN THE JEWETT BROOK WATERSHED

Several expected and unexpected changes occurred during the implementation of RCWP. The most significant and expected changes include: (1) 13 of 18 barnyards in the watershed were improved with RCWP cost-sharing funds; and (2) farmers managing 77 percent of the watershed installed animal waste storage structures with RCWP cost-sharing funds. These changes decreased the level of nutrients available for runoff and, thus, decreased the level of nutrients entering St. Albans Bay. A listing of all the BMP's implemented in the Jewett Brook watershed is presented in appendix table 1.

Some unexpected changes include: (1) corn acreage increased by 32 percent from 1982-85 although this may be merely the result of rotation cycles resulting in a disproportionate acreage of corn in 1985 compared with 1982; and (2) not all farmers complied with the guidelines presented in the farm contracts, according to farm surveys from the University of Vermont. This should be expected since farmers are limited by weather and field conditions and some exceptions are likely to occur each year. If farmers do not comply with nutrient management guidelines on a regular basis, water quality improvements are retarded.

The increase in corn acreage could occur if crop rotation cycles coincided for numerous fields or if farmers were not following contract guidelines. In either case, cornland differs from hayland in that it is more erodible, it receives higher fertilizer applications, and fertilizer on cornland is normally incorporated into the soil.

Appendix table 1--Number of farms with best management practices implemented in the Jewett Brook Watershed

| USDA BMP number | Best management practice | Farms implementing BMP |
|---|---|---|
| | | Number |
| 1 | Permanent vegetative cover system | 8 |
| 2 | Animal waste management system | 14 |
| 3 | Stripcropping system | 0 |
| 4 | Terrace system | 0 |
| 5 | Diversion system | 1 |
| 6 | Grazing land and protective system | 0 |
| 7 | Waterway system | 1 |
| 8 | Cropland protective system | 14 |
| 9 | Conservation tillage system | 0 |
| 10 | Stream Protection System | 8 |
| 11 | Permanent vegetative cover on critical areas | 12 |
| 12 | Sediment retention, erosion, or water control structures | 11 |
| 15 | Fertilizer management | 13 |

The benefits from any BMP are achieved only if they are properly implemented. Farm surveys for 1985 indicate that some farmers with animal waste storage structures continue to apply manure on cornland during the fall and winter or do not incorporate the manure in a timely manner. Almost 40 percent of the nutrient value can be lost when manure incorporation is delayed for 4 days because of nutrient runoff from cropland. While such practices may not violate contracts, it is to the farmers' advantage to implement nutrient management systems in the best manner possible. The results presented in this report are not influenced by the delay in incorporating spring applications of manure as long as they are incorporated before the June design storm. Winter and fall applications, however, influence the results just as they did for the 1982 design storms. The effect of delayed nutrient incorporation on water quality represents an area of research that could be useful for future nonpoint pollution program planning.

## APPENDIX II: THE AGNPS MODEL PARAMETERS

**Receiving Cell Number:** The number of the cell that receives the most significant portion of runoff from upslope cells. This was determined from topographical maps, channel maps from University of Vermont, and farm surveys.

**SCS Curve Number:** The weighted average of the hydrologic soil-cover complex numbers used by the Soil Conservation Service.

**Land Slope:** The average overland slope of the cell as determined from topographical maps and farm surveys.

**Slope Shape Factor:** Indicates the dominant slope shape of the cell. Data were not available, so a uniform slope was assumed for all cells.

**Field Slope Length:** Determined from the farm surveys whenever possible; otherwise the field slope length was determined from information provided in table 4 of the AGNPS user manual (37).

**Channel Slopes:** The average slope (percent) of the channels in the cell. Data were obtained from topographical maps. In cells without a channel, it was assumed that a series of small channels within the cell had a slope equal to half of the overland slope.

**Channel Sideslope:** The average channel sideslope (percent). No values could be measured so the default value of 10 percent was taken from the AGNPS user manual (37).

**Manning's Roughness Coefficient for the Channel:** A coefficient to indicate the roughness of the channel, based on land use conditions at the time of the storm. The land use for each cell was determined from the farm survey data, and coefficients were derived from the AGNPS user manual (37).

**Soil Erodibility Factor:** A soil-specific parameter from the universal soil loss equation was determined from the SCS Soil Survey at St. Albans Bay (32).

**Cropping Factor:** A parameter from the universal soil loss equation relating the effects of cover, crop sequence, and management practices. The cropping factor depends on the particular stage of growth and development of vegetative cover at the time of the storm (32).

**Practice Factor:** A parameter from the universal soil loss equation that "is the ratio of soil loss with a specific support practice to the corresponding loss with up- and down-slope culture" (32). The practice factor was obtained from farm surveys. In cases where the practice factor was not available in the farm surveys, it was assumed to be equal to one. Due to the relative flatness of the watershed, support practices affecting the practice factor such as contour farming, stripcropping on a contour, and terrace systems were generally not implemented, which results in a practice factor of one (32).

**Surface Condition Constant**: A constant based on land use at the time of the storm. It considers the time necessary for overland runoff to channelize (37).

**Aspect**: A single digit to indicate the direction of drainage from the cell.

**Soil Texture**: A classification of soil texture for the cell, which is determined from information provided by SCS and figure 6 of the AGNPS user manual (37).

**Fertilization Level**: A single-digit code to indicate high, medium, or low levels of fertiliztion. Rather than use three broad categories, the fertilization level was combined with the parameter for fertilization availability to delineate fertilization levels among fields.

The fertilization levels were determined from information provided in the farm surveys. When information concerning exact applications was unclear, fertilization calculations achieved were estimated based on the following guidelines: 1) a 1,000-pound dairy cow produces 90 pounds of manure daily (2); 2) field-available manure N and P ($P_2O_5$) per ton were assumed fixed at 5-2 for fall and winter applications and 7-2 for spring applications after animal waste management practices are in use. Spring manure applications can be incorporated into the soil at the time of application, thus, retaining more of the ammonia N. The farm contracts for the Jewett Brook watershed state that spring manure applications should be incorporated into the soil as soon as possible. Therefore, the 1985 fertilizer calculations were based on the higher manure nitrogen contents.

The levels of fertilization and the fertilizer availability adjustment factor are presented in appendix table 2. This adjustment factor is multiplied by the fertilizer availability parameter as a means to distinquish among the levels of fertilization.

Appendix table 2--Adjustment factors for nutrient availability

| Manure applied | N | $P_2O_5$ | Input | Availability adjustment factor |
|---|---|---|---|---|
| Tons/acre | Pounds per acre | | | |
| 10 | 60 | 20 | 1 | 1.00 |
| 15 | 75 | 30 | 2 | .75 |
| 20 | 100 | 40 | 2 | 1.00 |
| 25 | 125 | 50 | 3 | .63 |
| 30 | 150 | 60 | 3 | .75 |
| 35 | 175 | 70 | 3 | .88 |
| 40 | 200 | 80 | 3 | 1.00 |

**Availability Factor**: The percentage of fertlizer that is left in the top half inch of soil at the time of the storm. Availability factor varies with tillage practices (37). Since this report focuses on fertilizer applications and not on tillage practices, as previously mentioned, the availability factor was multiplied by the nutrient availability adjustment factor as presented in appendix table 2.

**Point Source Indicators**: Indicates if there is a barnyard in the cell. If there is a barnyard, further information is input. Barnyard data include the acreage of the barnyard adjoining tributary and buffer areas, curve numbers for these areas, and number and type of animals using the barnyard. The parameters for the buffer area below the barnyard include the land slope, vegetative or other cover, and the distance from the barnyard to the nearest discharge point.

**Gully Source Level**: An optional parameter that was not used in this study. No significant gullies exist in the Jewett Brook watershed, due primarily to its relatively flat topography.

**Chemical Oxygen Demand**: COD is based on the land use in the cell. COD values for Minnesota were used because COD values for Vermont were not available. Farmland in Vermont and Minnesota should have comparable background COD values given the climatic and land-use similarities between the two States (1). COD values are available in Young's report (37).

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